2006 DOE Hydrogen Program Review

Hydrogen Transition Modeling and Analysis HyTrans v. 1.5

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Overview: Our Overall Goal is to Identify and Evaluate Transition Scenarios

Timeline

- Start: 10/1/2004
- Finish: 10/31/2007
- Status: 60% completed

Barriers

- Transition Scenarios
  - "By 2007, identify and evaluate transition scenarios, consistent with developing infrastructure and hydrogen resources, including an assessment of timing and sequencing issues." p. 4-1

Budget

- FY05 - $450K
- FY06 - $XXXK

Partners

- ANL – Pipelines & delivery
- NREL & H2A – Production & delivery, spatial demand
- UC Davis, others - Expert review

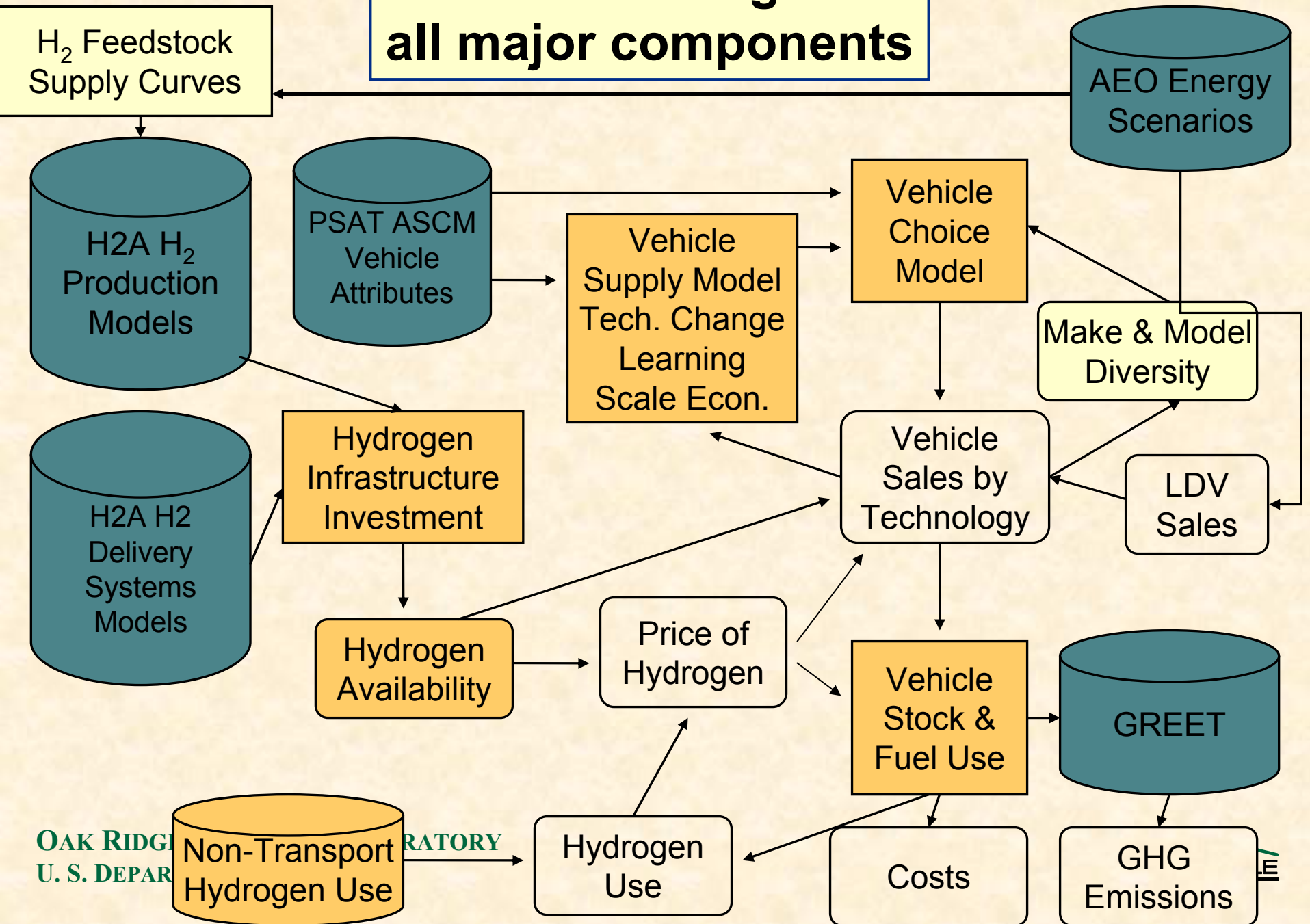
Objectives:
Model the market transition to a H2 vehicle system in a way that is useful for R&D planning, cost-benefit analysis, policy analysis and envisioning.

- Integrates all main H_2 market components
  - Hydrogen Production
  - Hydrogen Delivery
  - Vehicle Production
  - Consumer Choice
  - Hydrogen Use
- Determines a market equilibrium solution
  - Maximizes total consumption benefit minus production, distribution, and other costs
  - Estimates amounts and timing of costs, benefits, levels of investment and activity, production and consumption, key environmental impacts.
  - Sensitive to technological goals and supporting policies.

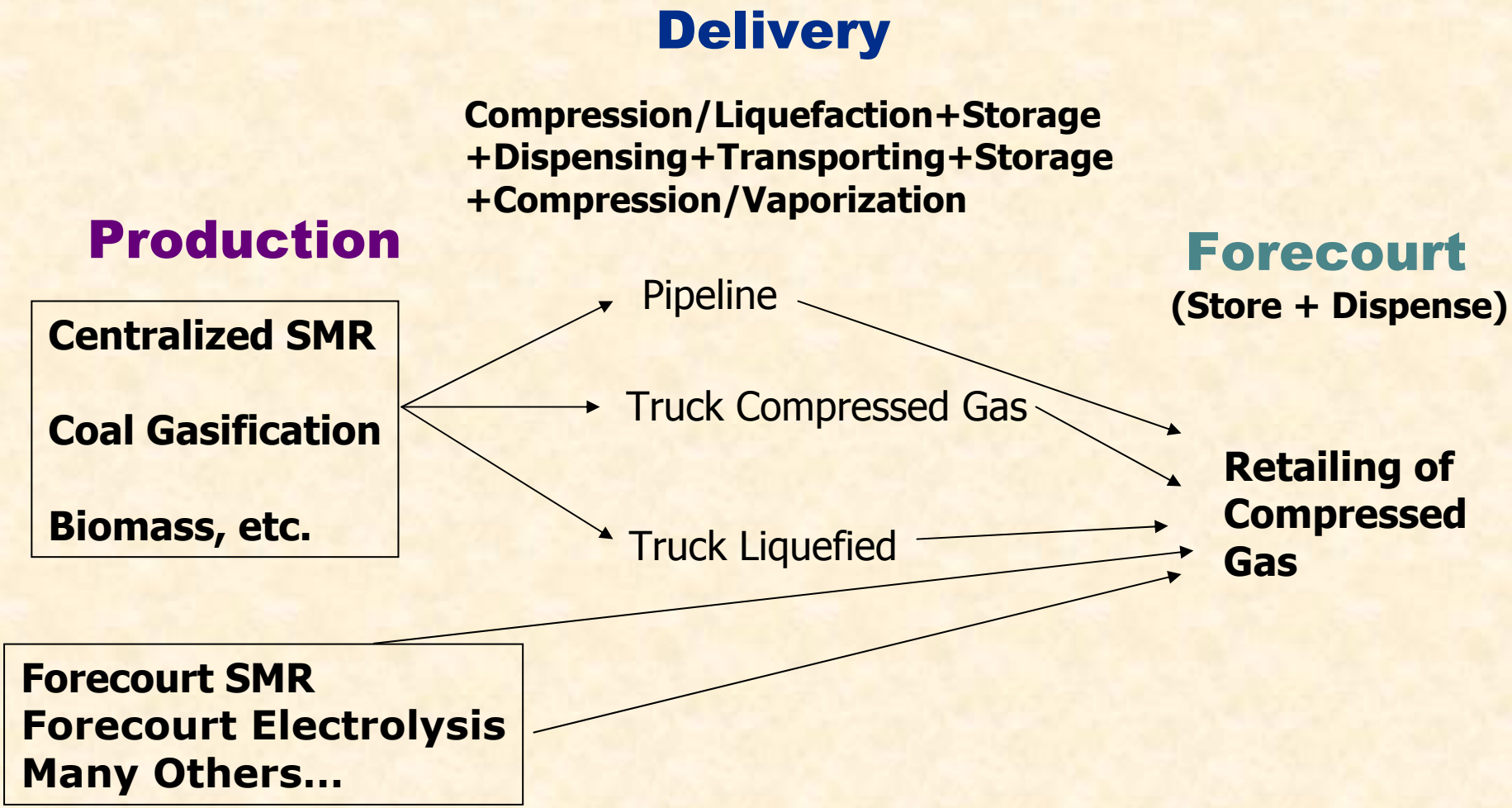
Our method is economic modeling via non-linear optimization.

- Production pathways: cost functions
- Vehicle production: cost functions
- Consumer demand: NMNL
- 3 fuel demand density regions
- Key dynamic elements:
  - Learning-by-doing
  - Technological change
  - Scale economies
  - Fuel availability
  - Diversity of vehicle choices
- Generalized Algebraic Modeling System

HYTRANS integrates all major components



A H2 Supply Pathway comprises three parts.



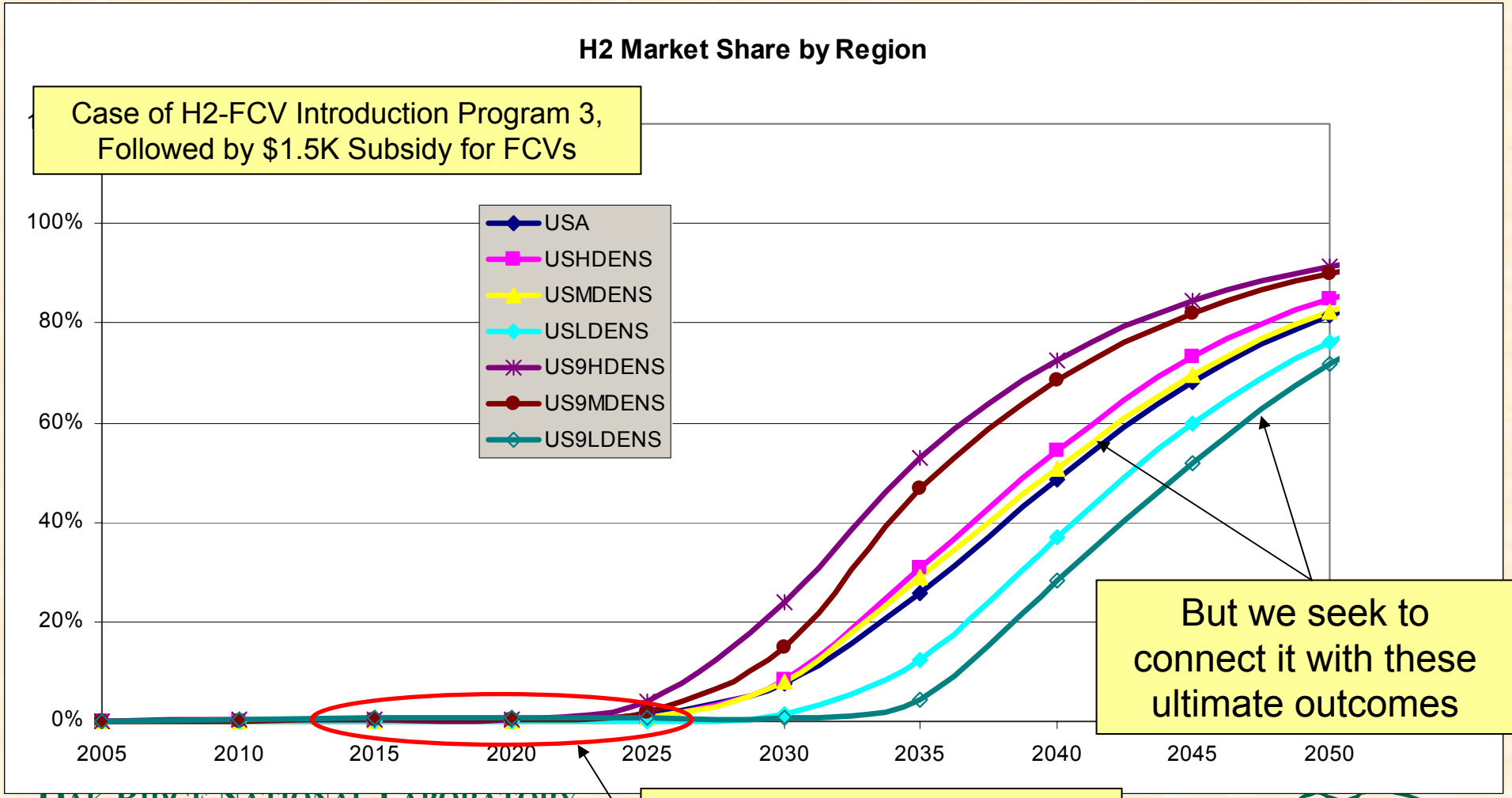
Accomplishments: Enhancements to allow more realistic modeling of the early transition to hydrogen.

- Added representation of West-coast (region 9) and rest of U.S.
- Added representation of supply from existing H2 production facilities in R9.
- Developed method for solving year-by-year in the early years
- Develop accurate reduced-form representation of the H2A Delivery Model
- Add more regions & metropolitan areas
- Expand representation of regional feedstock supply
- Improve representation of existing H2 supply, extend to all U.S.
- Improve representation of manufacturers' decision making, introduction of makes & models
- Improve representation of fuel availability
- Link to/establish consistency with NREL detailed GIS analysis

Two recent FY 2006 achievements.

- Development of a method for solving year-by-year in the early years.
  - Connects to 5-year solution periods in future
  - Allows greater realism and detail in early years
  - Facilitates moving window of limited foresight
- Development of an accurate reduced-form representation of the H2A Delivery Model
  - Predicts unit costs with 1-2% accuracy
  - A function of total H2 demand, city area, station size
  - Required reformulating how we represent the geographical evolution of demand and supply

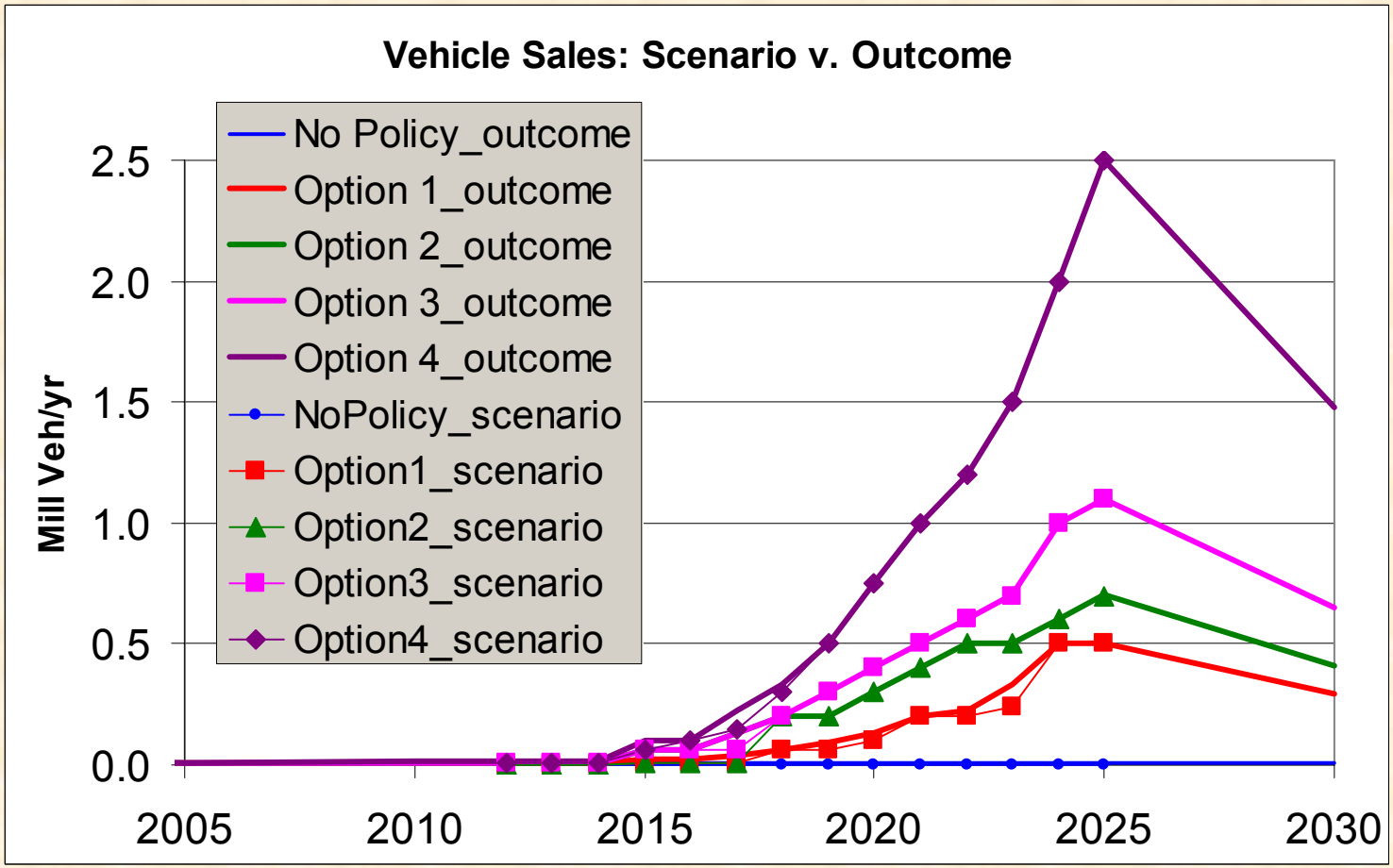
For better market transition analysis, we needed a more precise representation of the small numbers of the early transition.



Increased resolution in early period while maintaining connection to long-term future at 5-year intervals.

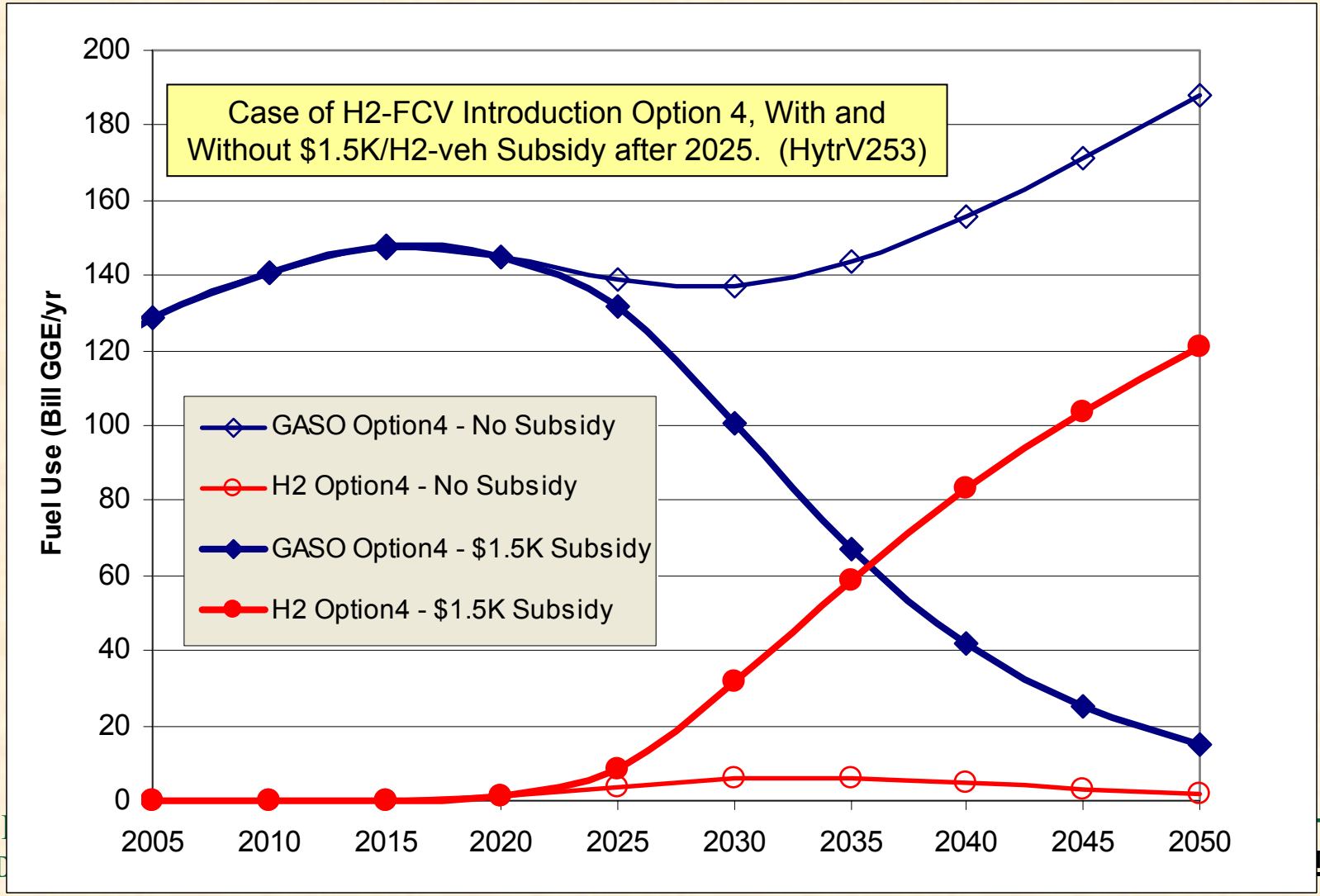
- Increased numerical resolution of key variables at small values (early vehicle sales and fuel production)
- Introduced shorter time steps in early periods (e.g. annual) and variable time step later to keep long planning horizon *and* modest model size
- Greater geographical resolution in R9 (e.g., LA is LA).

HyTrans is now much more accurate in the period from 2010 to 2025, with annual detail at an acceptable computational cost.

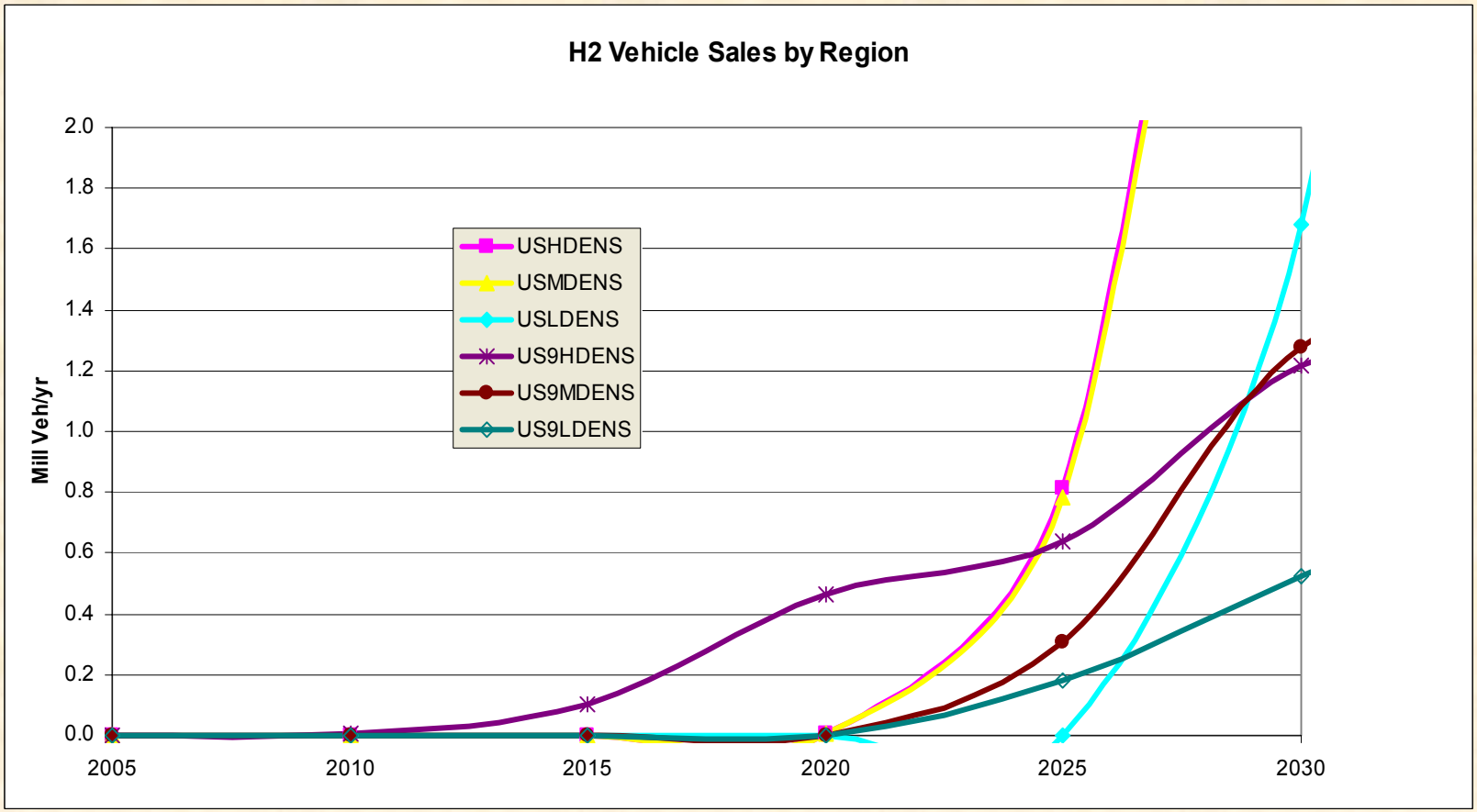


Case of H2-FCV Introduction Options 1-4, With No Other Subsidy or Policy. (HytrV253)

HyTrans is able to evaluate Scenarios with combinations of market introduction strategies and subsidies, with incentives varying over time



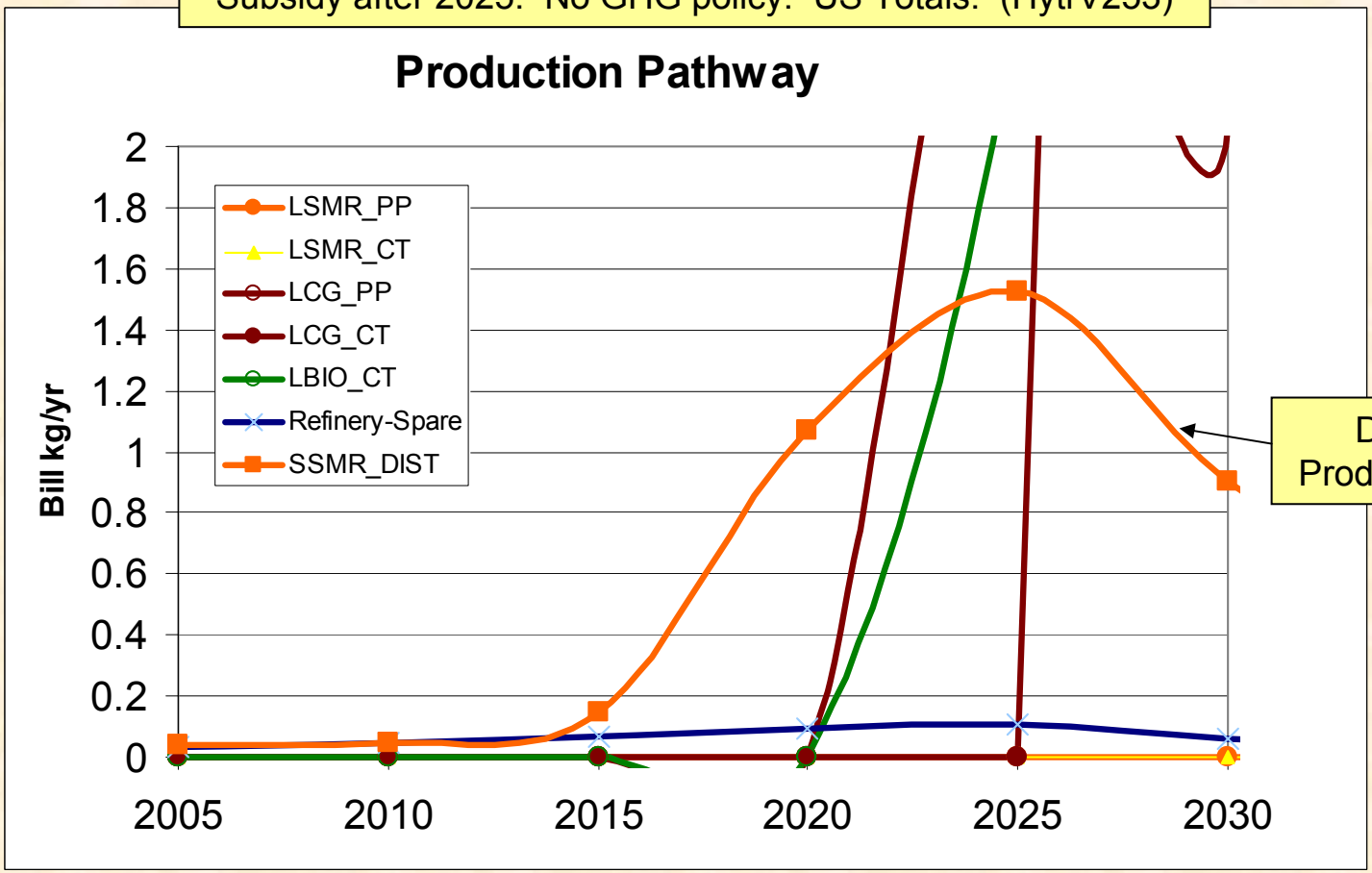
Early H2 Vehicle Sales Match Program (through 2020). 2025 and Beyond, Market Expands Rapidly (With H2 Veh. Subsidy)



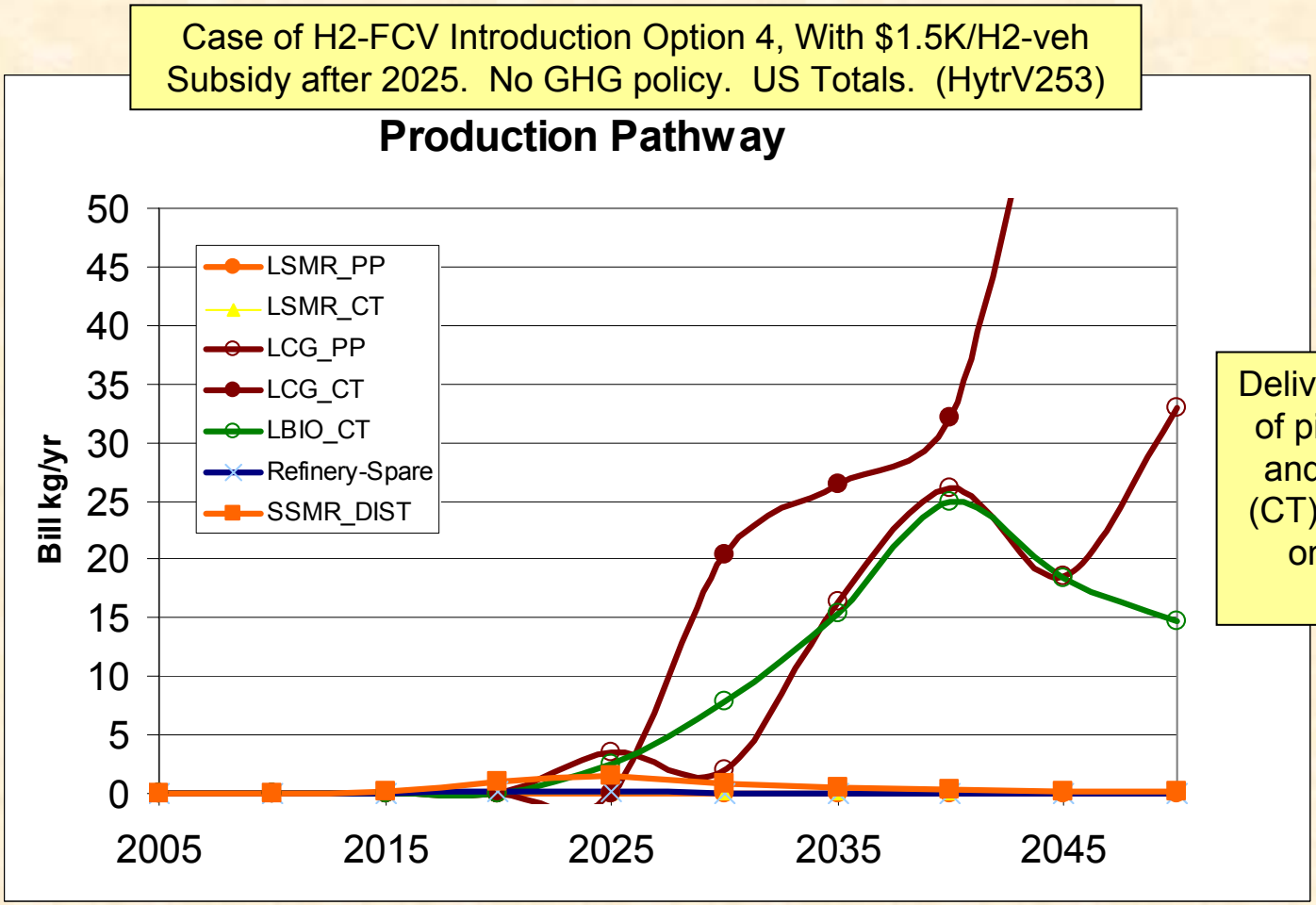
Case of H2-FCV Introduction Program 3, Followed by $1.5K Subsidy for FCVs

Production begins with available refinery/merchant capacity, and distributed SMR

Case of H2-FCV Introduction Option 4, With $1.5K/H2-veh Subsidy after 2025. No GHG policy. US Totals. (HytrV253)

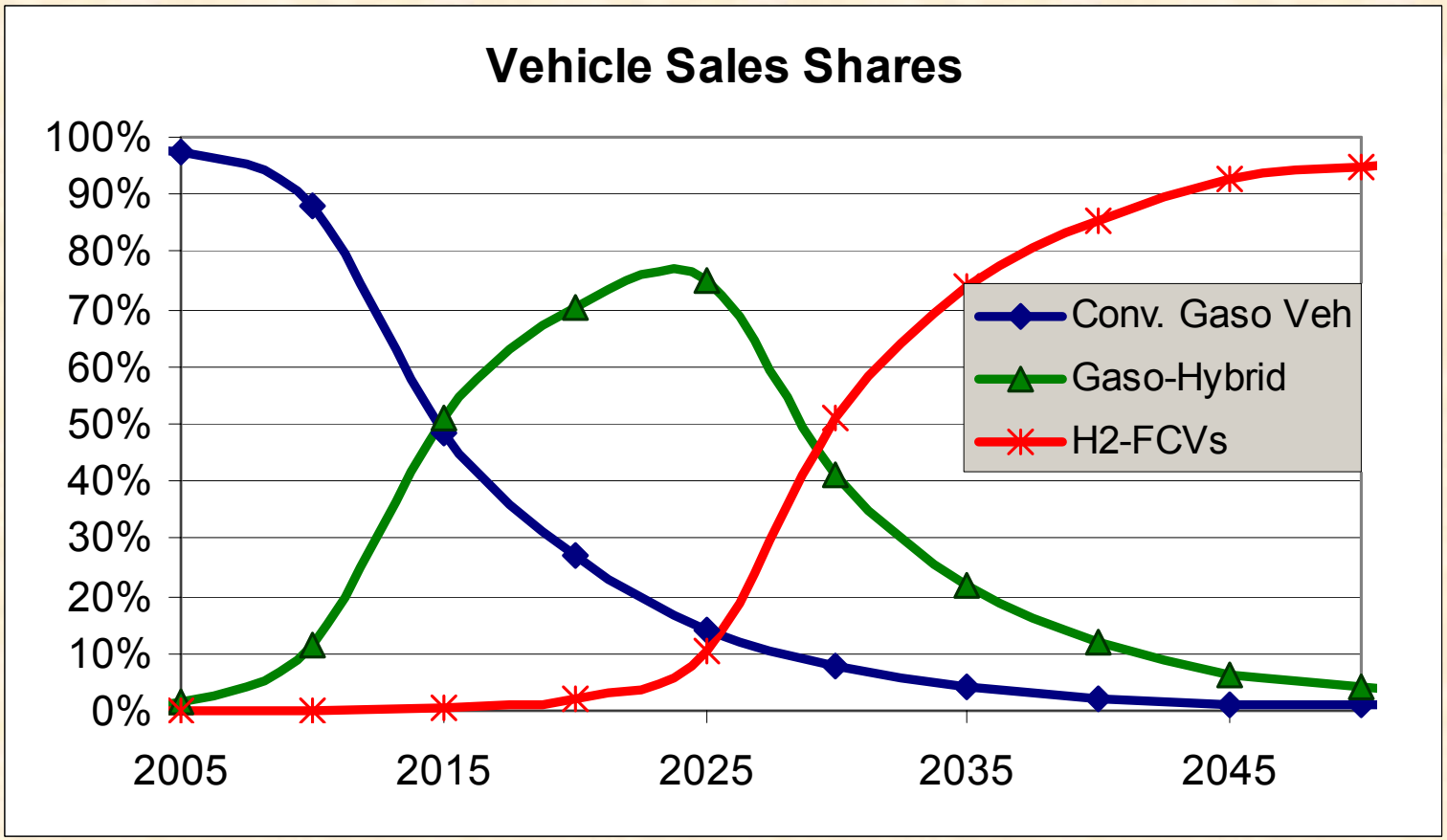


Following distributed SMR, full market develops (in this case) from Centralized Coal and Biomass Gasification.



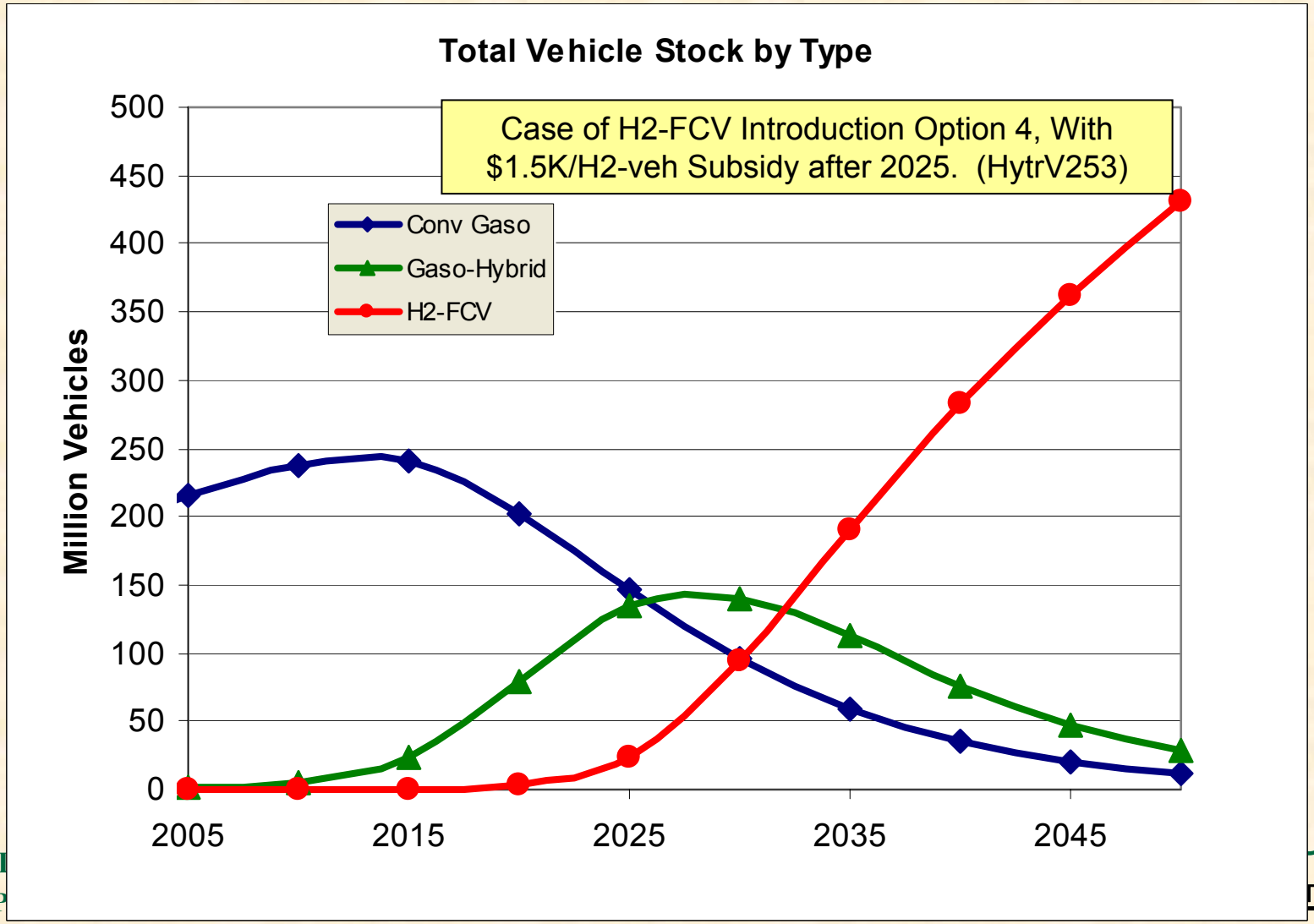
Delivery is by mix of pipeline (PP) and cryo-truck (CT), depending on regional density

Developing Scenarios: E.g. Early H2 Vehicle Program Coupled With Post-2025 Subsidy ($1.5K), H2 Vehicles Can Displace HEVs

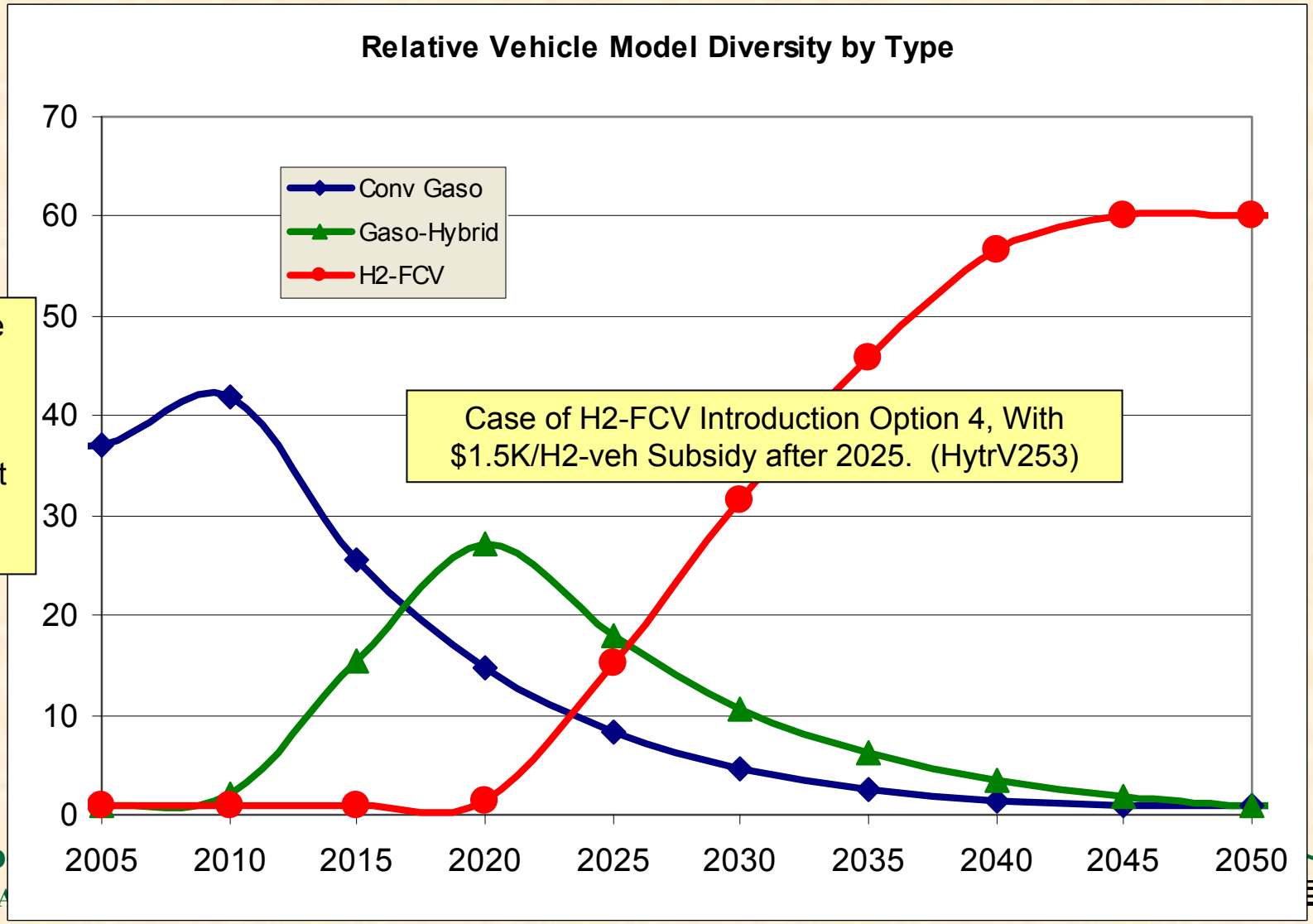


Case of H2-FCV Introduction Program 3, Followed by $1.5K Subsidy for FCVs

Vehicle Stock by Type: Transition to H2 Vehicle System Takes over decades, with Hybrid-Electric Vehicle as Intermediate Technology

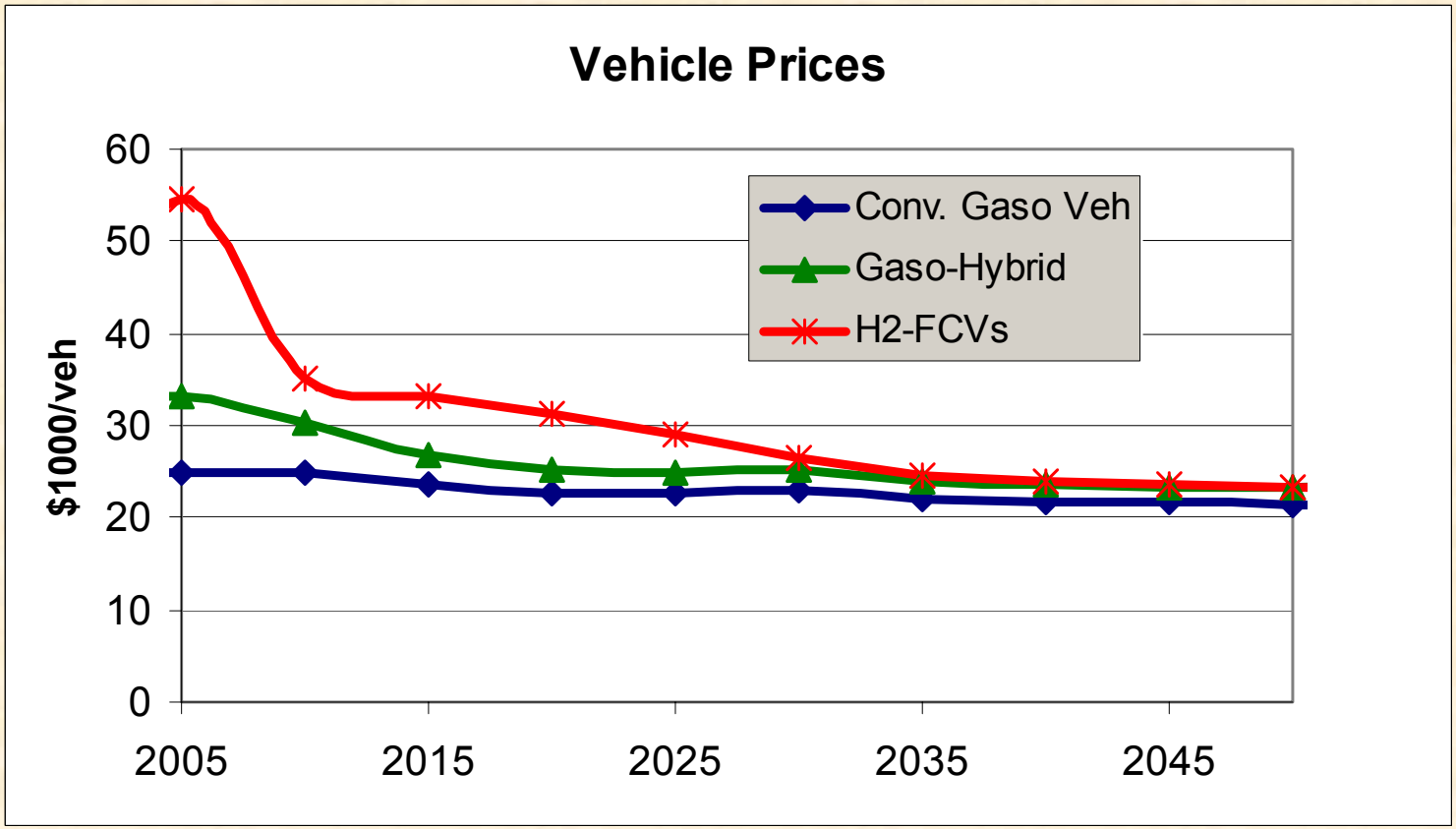


Relative Vehicle Make-and-Model Diversity Varies with New-Vehicle Market Share



A measure of broad vehicle platform groups, not detailed models

H2 Vehicle Prices Decline Rapidly Early Under Program (through 2025), Eventually FCVs, Hybrids & Gasoline CV are Priced Near Parity



Case of H2-FCV Introduction Program 3, Followed by $1.5K Subsidy for FCVs

Allowing variable time increments was an important methodological breakthrough.

- Allows greater realism in early period where policies will play a crucial role.
- Facilitates alternatives to perfect foresight formulation:
  - Can move year-by-year window forward in time more realistically representing limited planning horizons.
  - Connect year-by-year window to future represented in 5-year increments. Even if agents imperfectly perceive future, accounting of future stocks, flows necessary.

We have estimated accurate reduced form equations representing the H2A Delivery Systems Model.

- Break each process into cost components.
- Each component depends on “city” demand for H2, city area and station size (capacity utilization = 1).
- Prediction errors of about 1-5% versus ANL spreadsheet model, in most cases 1-2%.
- Forced us to rethink our entire representation of regional demand and supply, but that’s good.

The general functional form is a sum of component costs which vary chiefly with scale and delivery distance (sqrt(area)).

$$UC = \sum_{i=1}^{n} X_i \left(\sum_{j=1}^{m_i} a_{ij} Y_j^{\alpha_{ij}} \right)$$

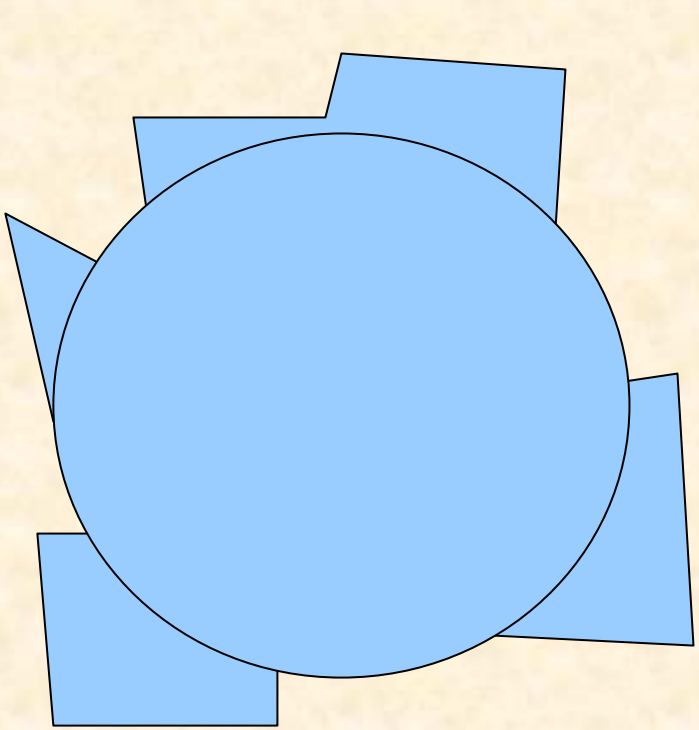
UC = unit cost of hydrogen delivery

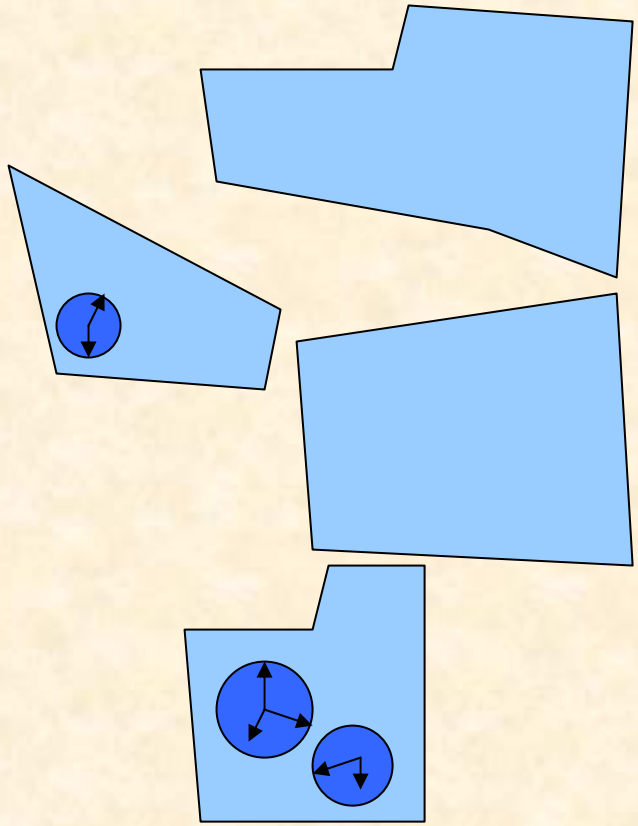
X_i = cost component i

Y_j = value of variable j

(City H2 Use, City Area, Forecourt Size, Forecourt Capacity Utilization =1)

The new spatial model of supply and demand is more realistic. Instead of "delivering" to the aggregated (circular) region, only parts of the region are served, and incrementally.





The US (& region 9) is divided into 3 fuel demand density regions. The delivered cost of hydrogen depends on density via quantity of demand and delivery distance (square root of area).

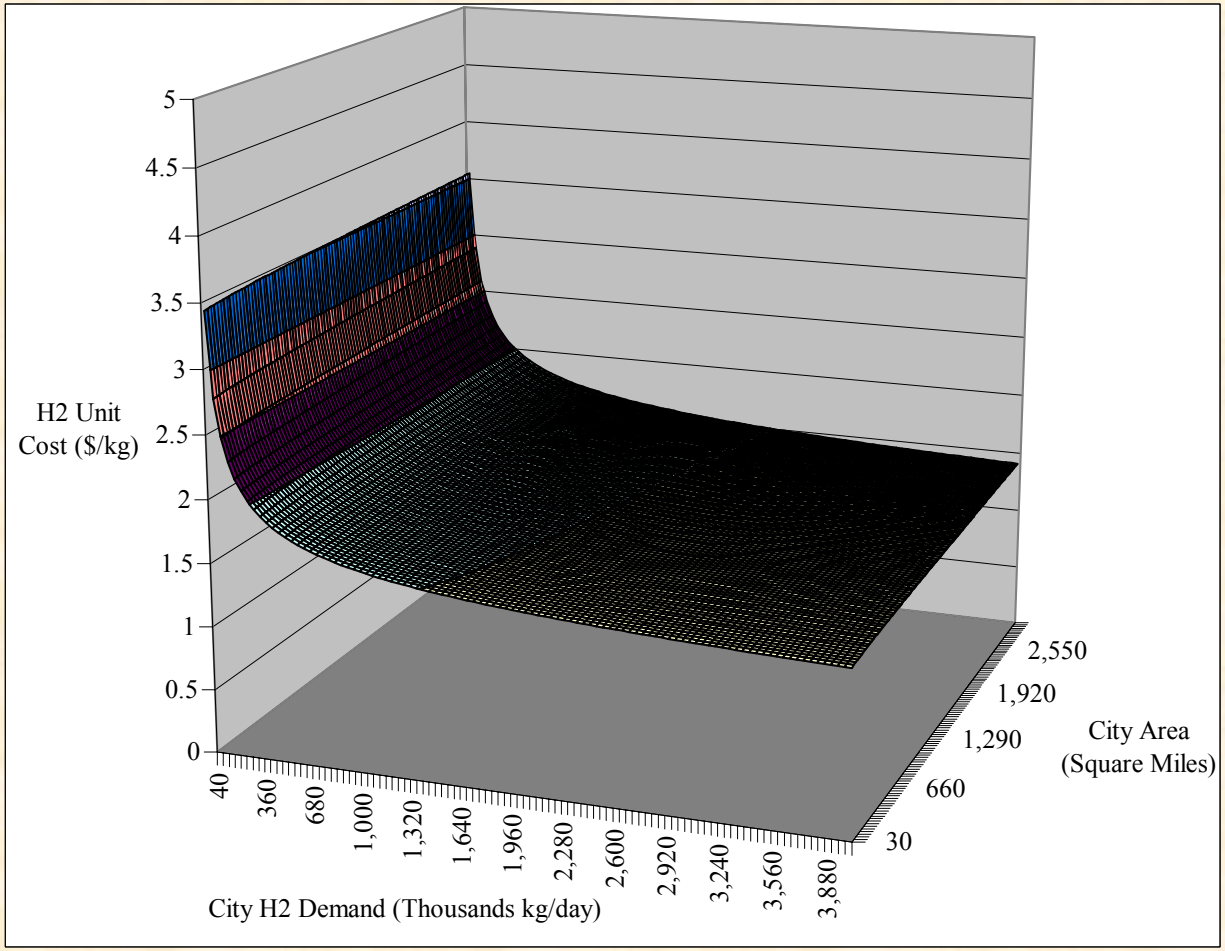
According to EPA data, 2/3 of LDV fuel is used in <10% of the land area.

UT-BATTELLE

We added a separate representation of region 9, including existing H2 production. The two high fuel demand density areas in Region 9 are LA and the Bay Area (>240,000 kg/km^2/year).

A spreadsheet model we have distributed to NREL and other colleagues summarizes our reduced form version of the delivery model.

Estimated H2 Unit Costs by Delivery Mode, City H2 Demand, City Area, and Retail Station Size

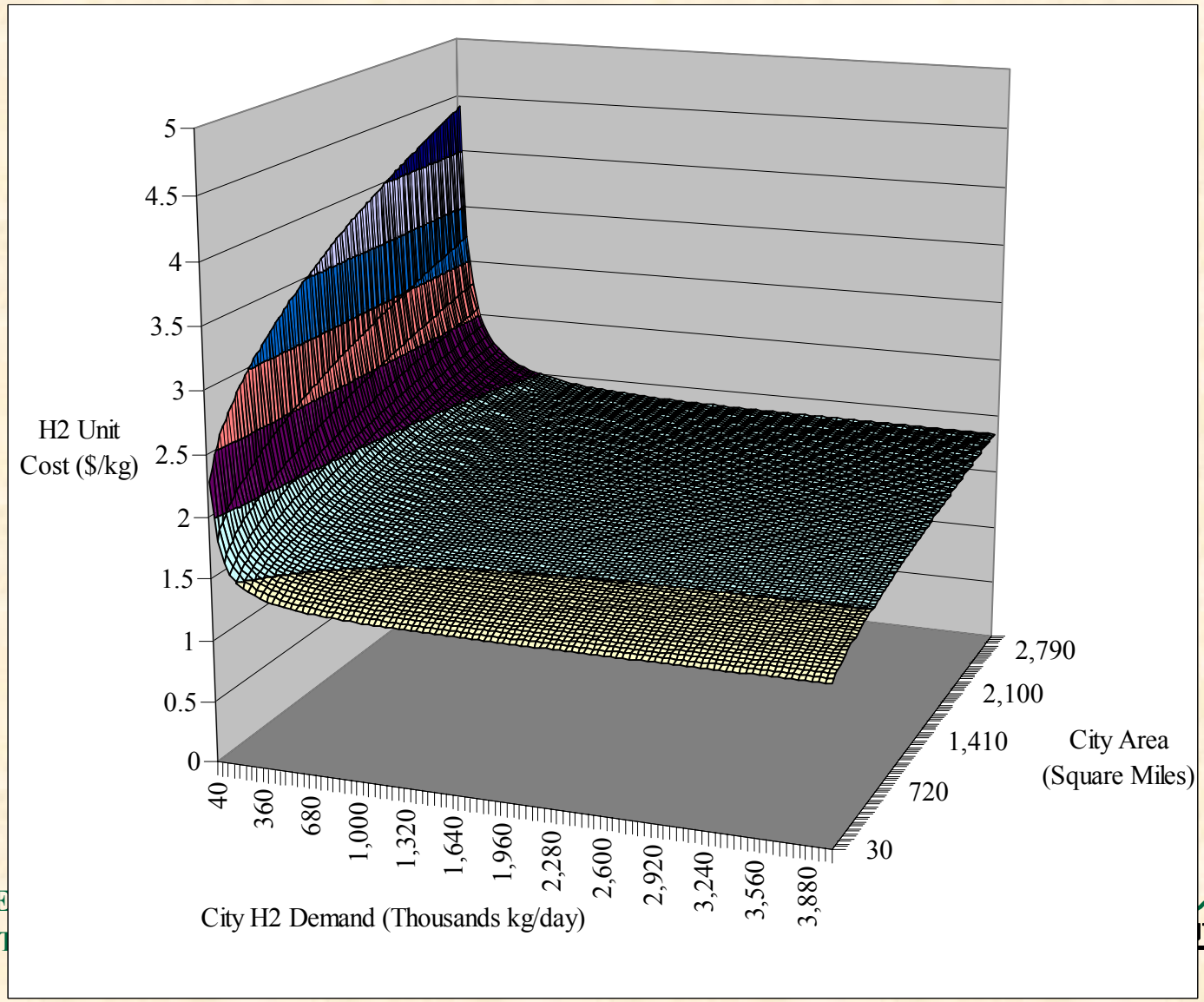


Delivery Mode	Liquid Trucks
Include Forecourt Costs?	TRUE
Retail Station Size	1,500 kg/day
Distance from production to city	0 Miles

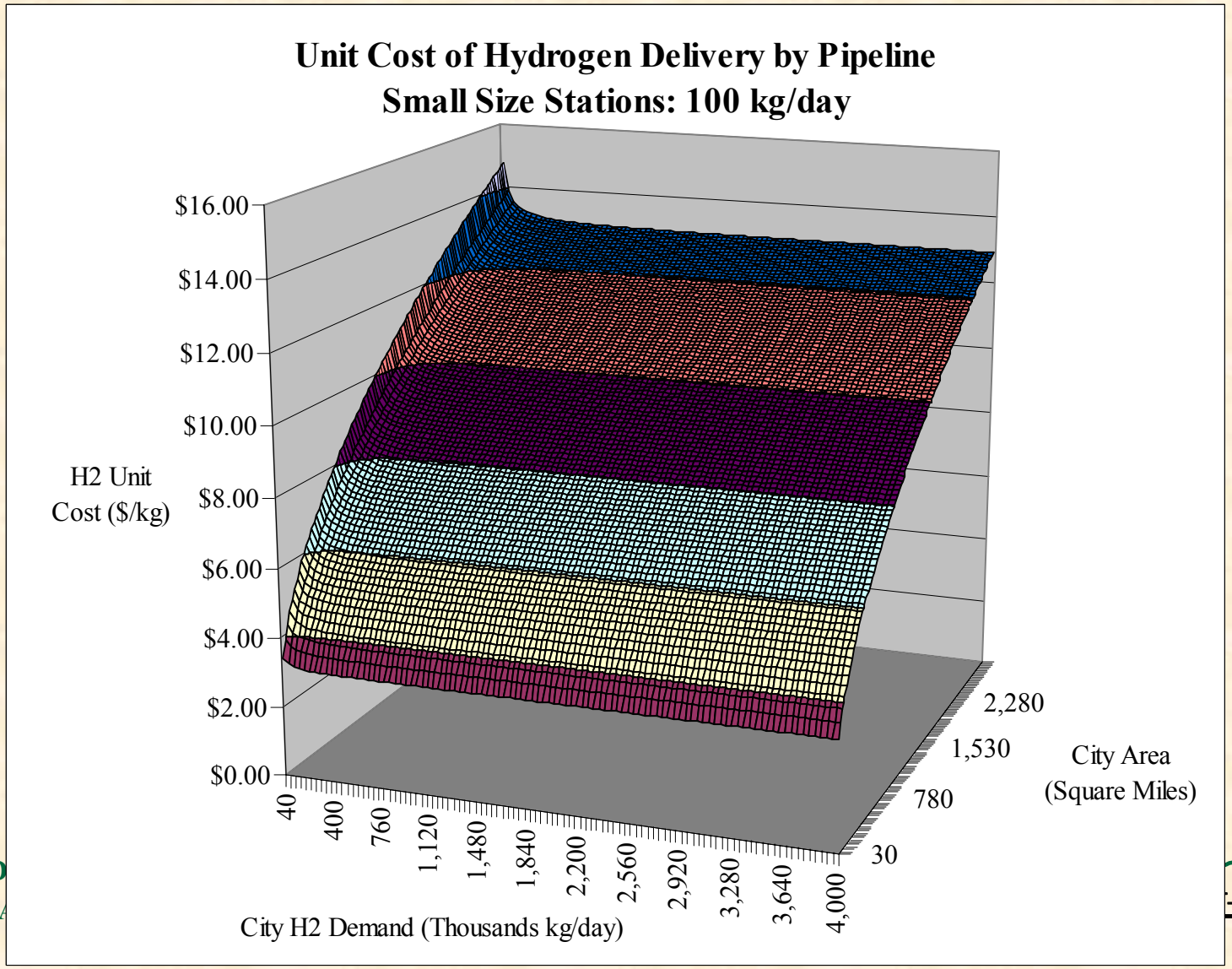
Least Cost Delivery Mode

City H2 Use (1000 kg/day)	City area (square miles)	Least Cost Delivery Mode
40	30	Pipelines
	1020	Pipelines
	2010	Gaseous Trucks
	3000	Gaseous Trucks
1320	30	Pipelines
	1020	Liquid Trucks
	2010	Liquid Trucks
	3000	Liquid Trucks
2800	30	Pipelines
	1020	Liquid Trucks
	2010	Liquid Trucks
	3000	Liquid Trucks
4000	30	Pipelines
	1020	Liquid Trucks
	2010	Liquid Trucks
	3000	Liquid Trucks

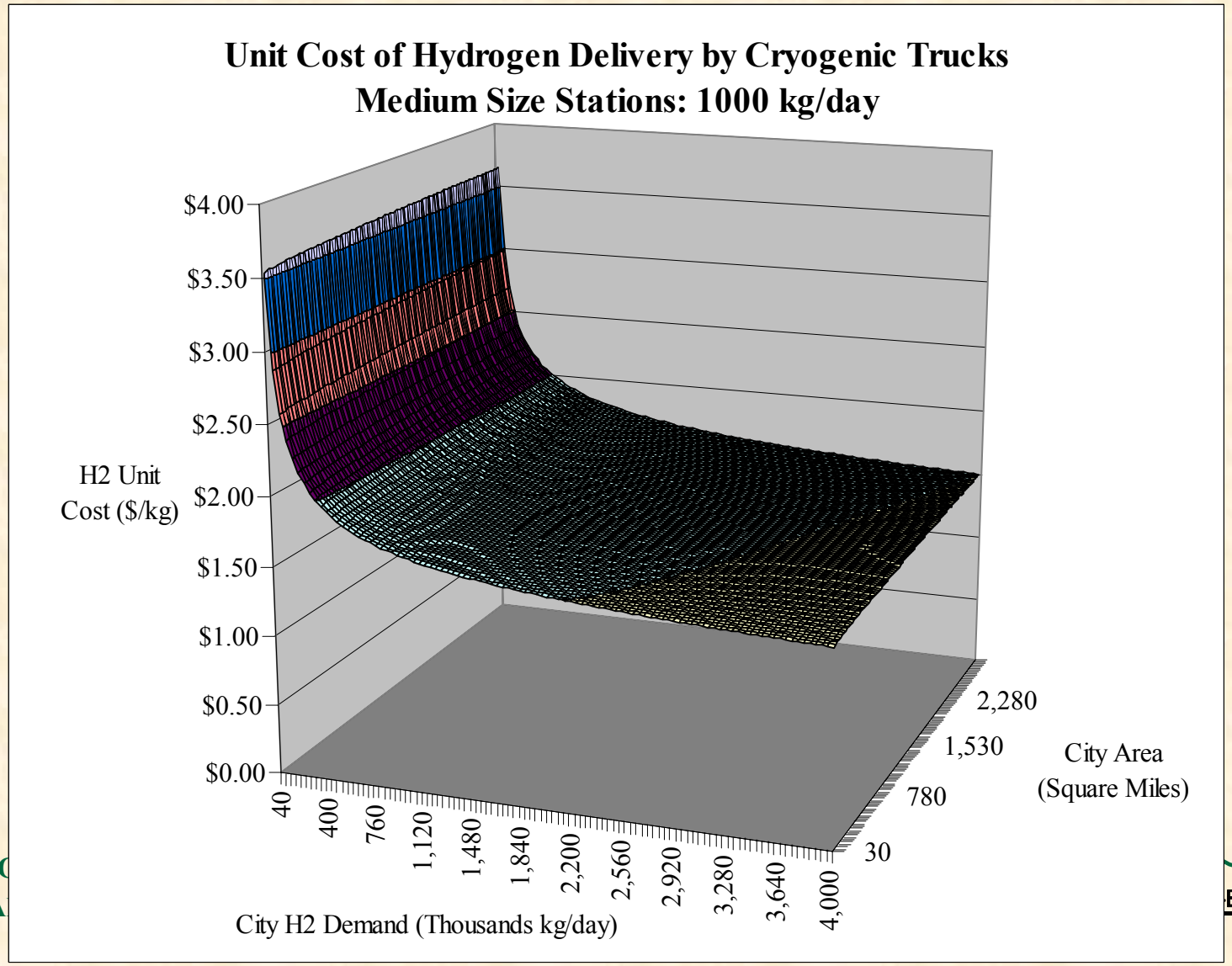
Pipelines with 200km access, costs of 1,500 kg/d forecourts included.



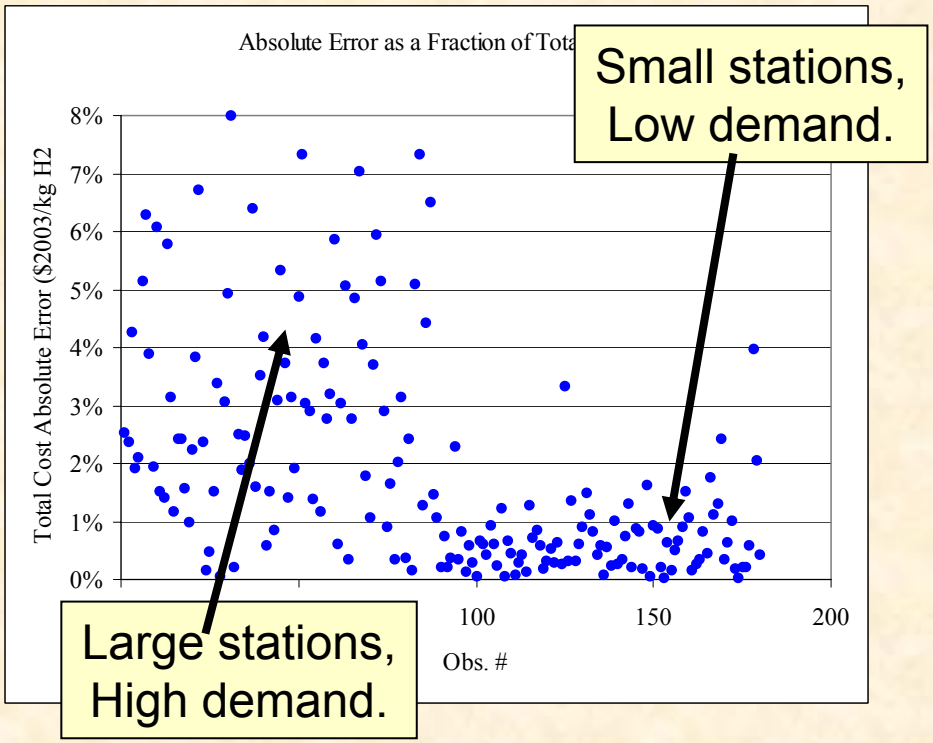
Serving very small forecourts by pipeline is expensive, with costs increasing rapidly with city size and not strongly dependent on market penetration.



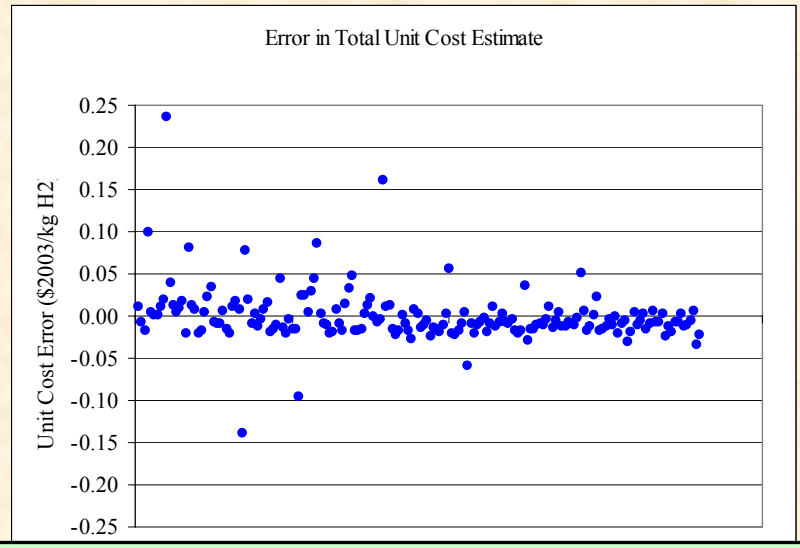
With station size increased by a factor of 10, costs come down by about ½.



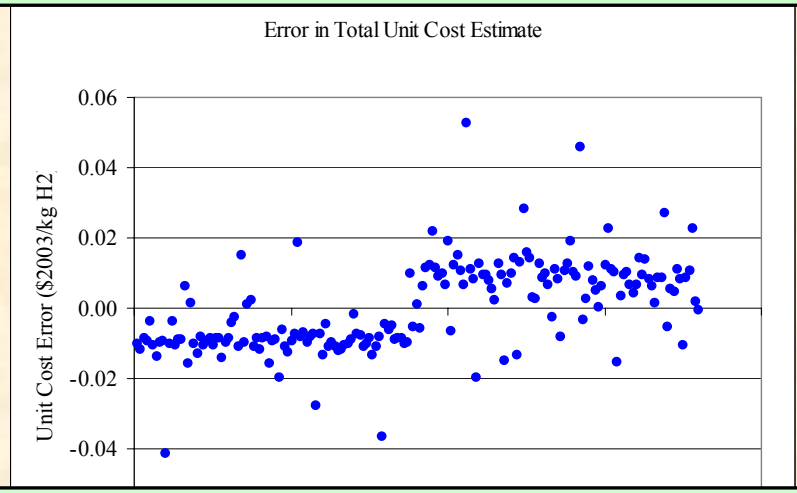
Reduced Form Delivery Model Approximation Errors are Quite Small



Pipeline delivery cost errors generally less than $0.10/kg (1%-5%)



Prediction errors for gaseous truck delivery are very small, <$0.05/kg.



Liquid truck delivery costs are the most accurate of all, <$0.02/kg

HyTrans is making significant progress.

- Plausible answers to:
  - Is a stable transition achievable?
  - When?
  - How long will it take?
- Can begin to test key policies
- Produces potentially useful cost and benefit measures
- Close to useful visions of the transition
- Beginning to generate insights about R&D goals
  - Good enough?
  - Effects of competing technologies

Significant improvements to HyTrans will be made in 2006.

- Initial realistic early transition scenarios by June 2006. Coordinate with NREL's detailed geographical analysis.
- Add more regions, beginning with NE states
  - Add more regional feedstock supply curves.
  - With NREL, add renewable regional feedstock supply curves.
- Complete implementation of delivery model.
- Enhance representation of
  - fuel availability .
  - consumer choice: early adopters. Exclusive meetings with auto manufacturers in CA.
  - technological progress, scale economies, learning-by-doing, manufacturer decision making.
- Incorporate alternatives to complete information.
- Update calibration to AEO 2006

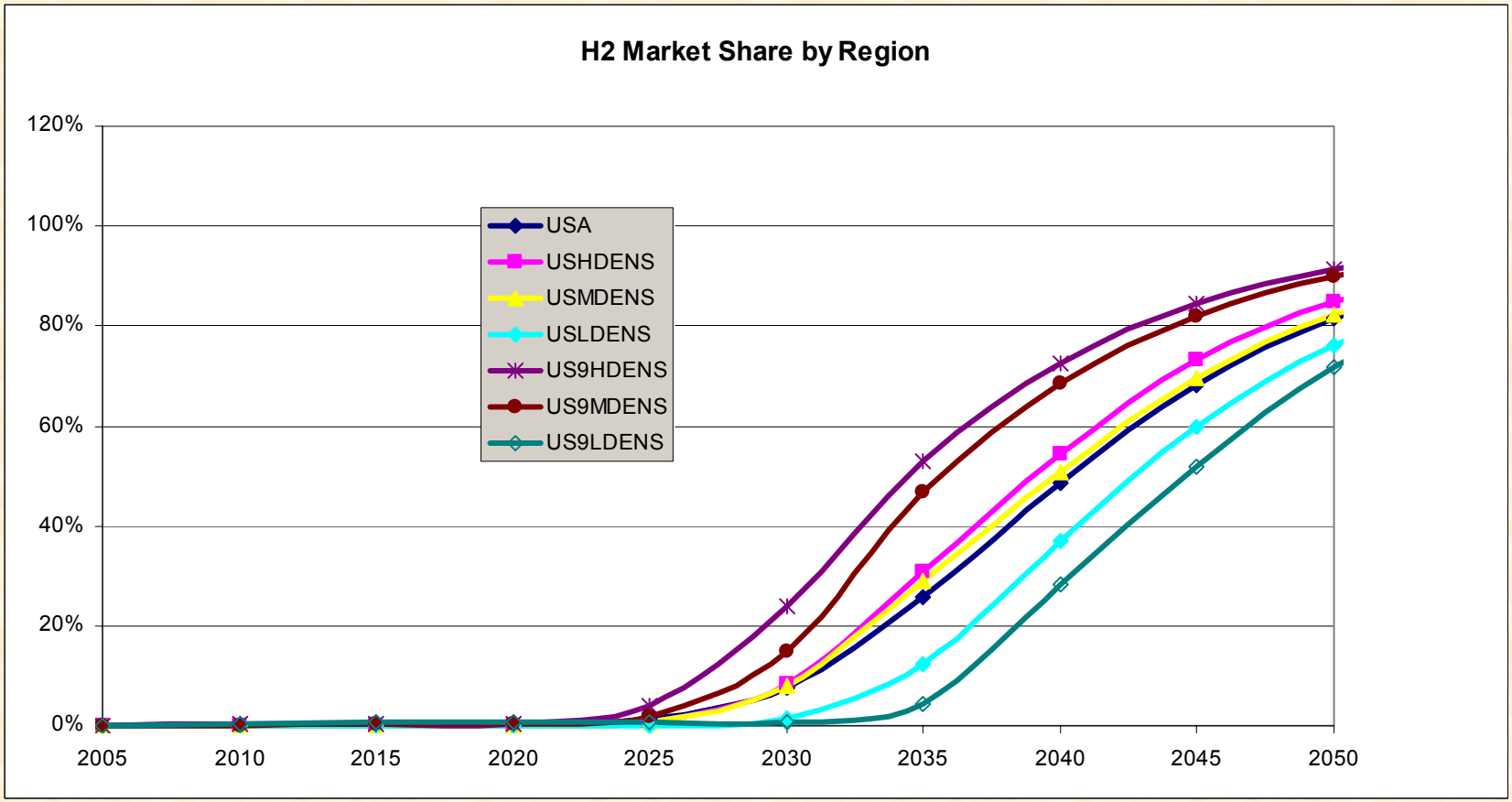
THANK YOU.

Backup Slides

These scenarios are provided for transition analyses as recommended by the National Research Council to evaluate the transition phase and do not represent any specific policy recommendation.

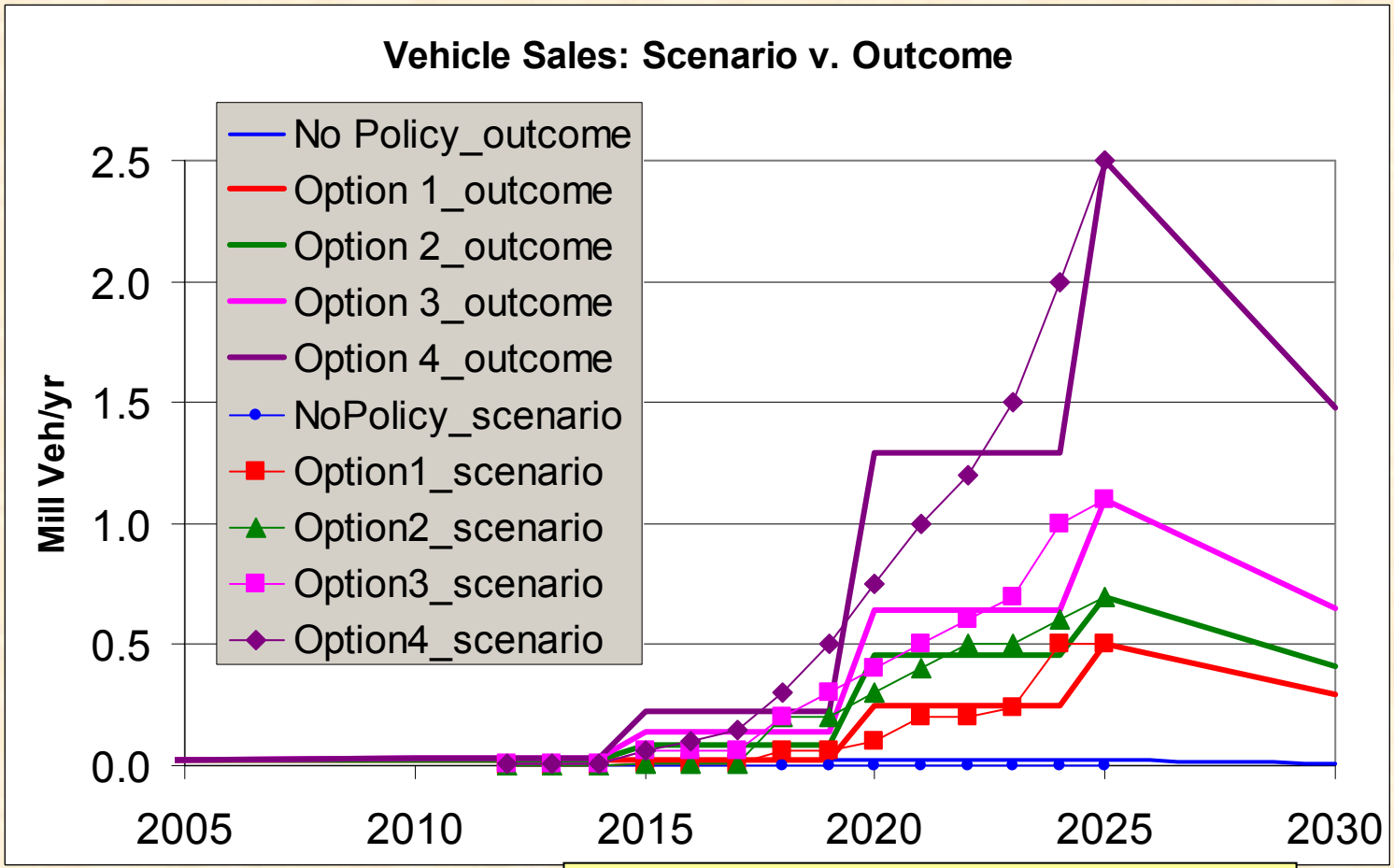
Government Support - Program Options (in thousands of vehicles)															
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Option 1				5	5	5	60	60	100	200	200	240	500	500	1.8M
Option 2				5	5	5	200	200	300	400	500	500	600	700	3.4M
Option 3	5	5	5	60	60	60	200	300	400	500	600	700	1000	1100	5.0M
Option 4	5	5	5	60	100	150	300	500	750	1000	1200	1500	2000	2500	10.0M

H2 Market Penetration Starts in Highest Density (Urban) Area, Region 9. Spreads to Medium Density R9, Then Rest of USA



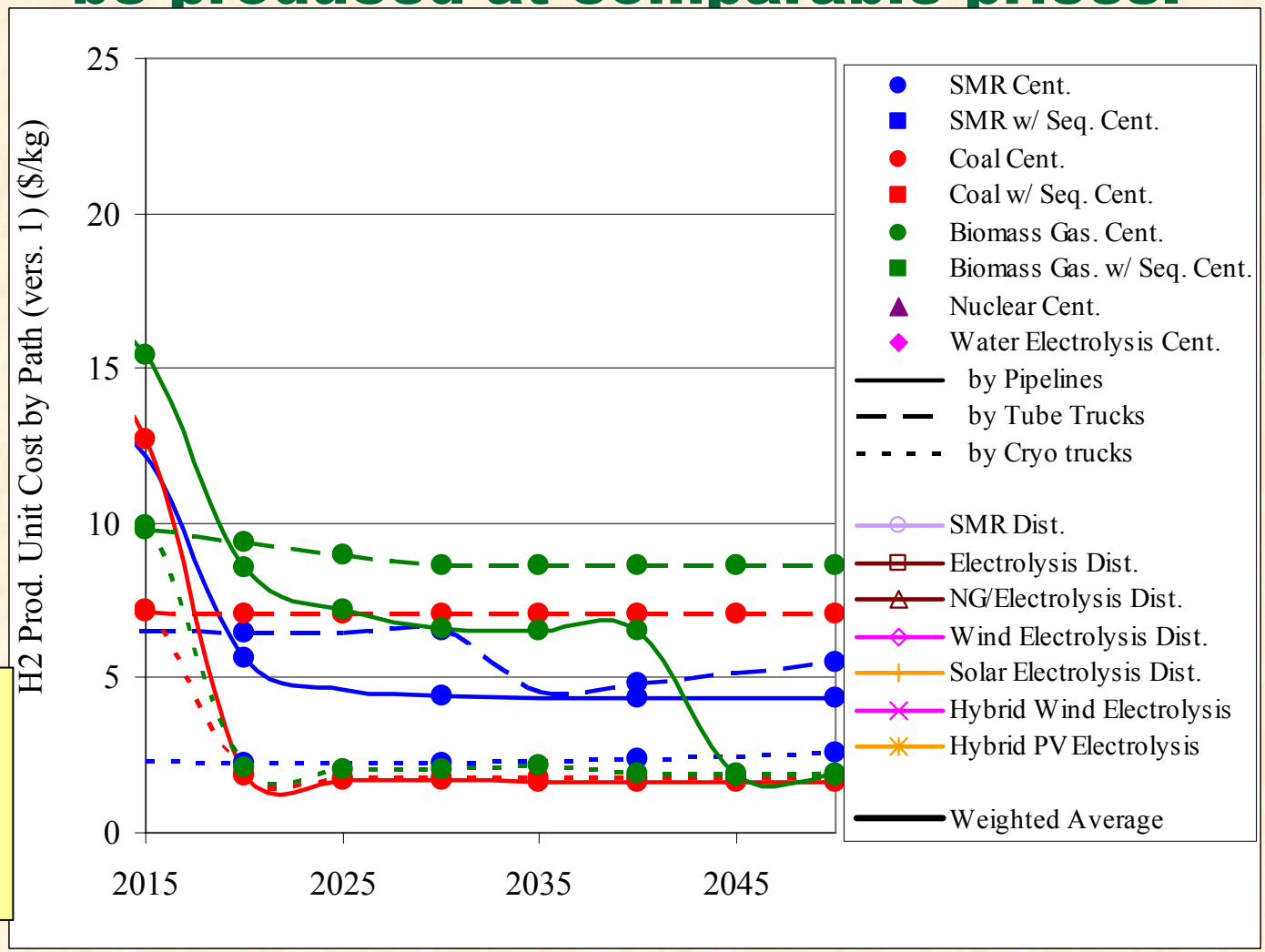
Case of H2-FCV Introduction Program 3, Followed by $1.5K Subsidy for FCVs

Previous HyTrans versions with 5-year intervals crudely approximated the four DOE scenarios in which vehicle sales were < 1% of total U.S. sales.



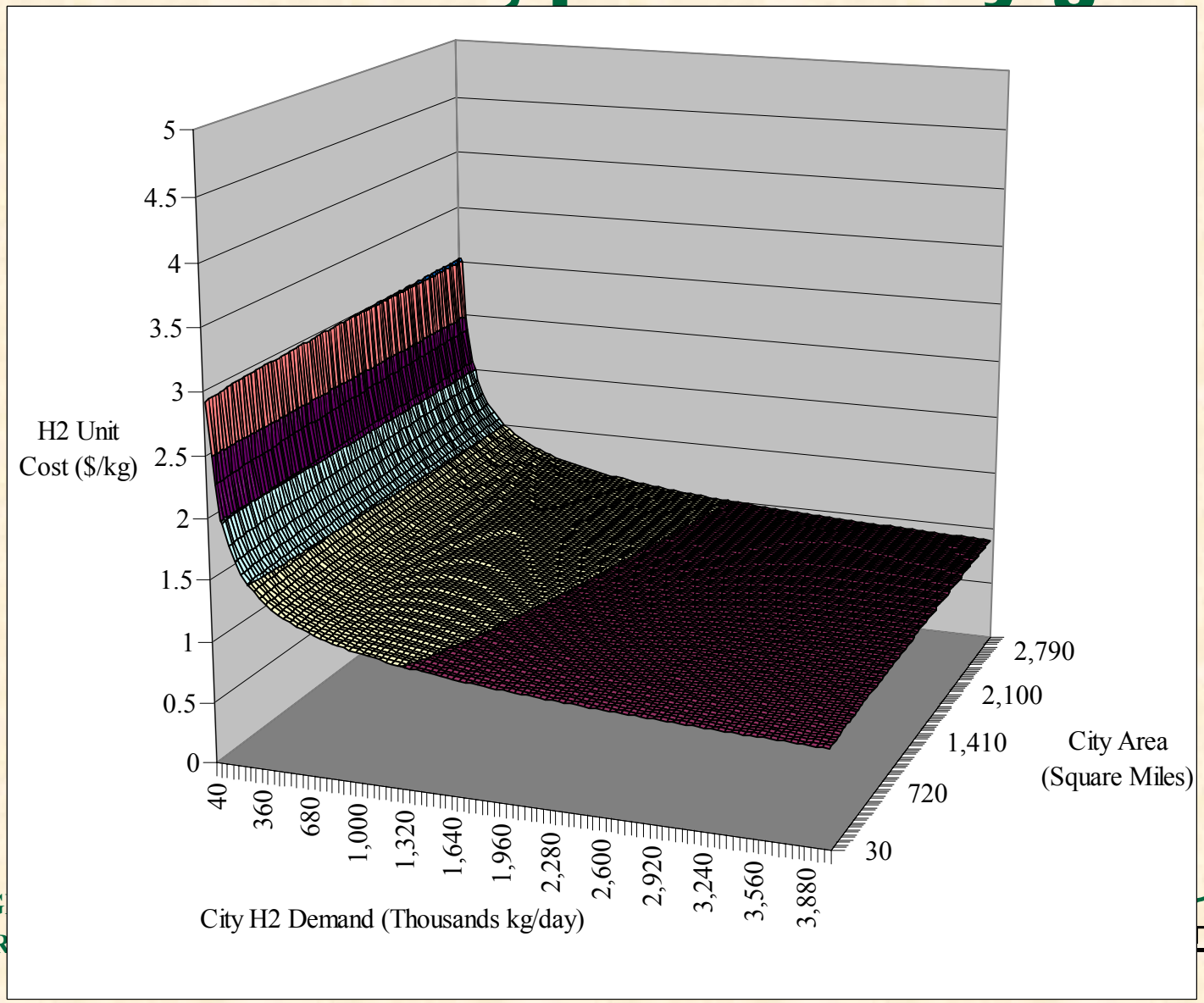
Case of H2-FCV Introduction Options 1-4, With No Other Subsidy or Policy. (HytrV251)

Alternative H2 Pathway Costs: According to H2A, Coal, SMR and biomass can be produced at comparable prices.

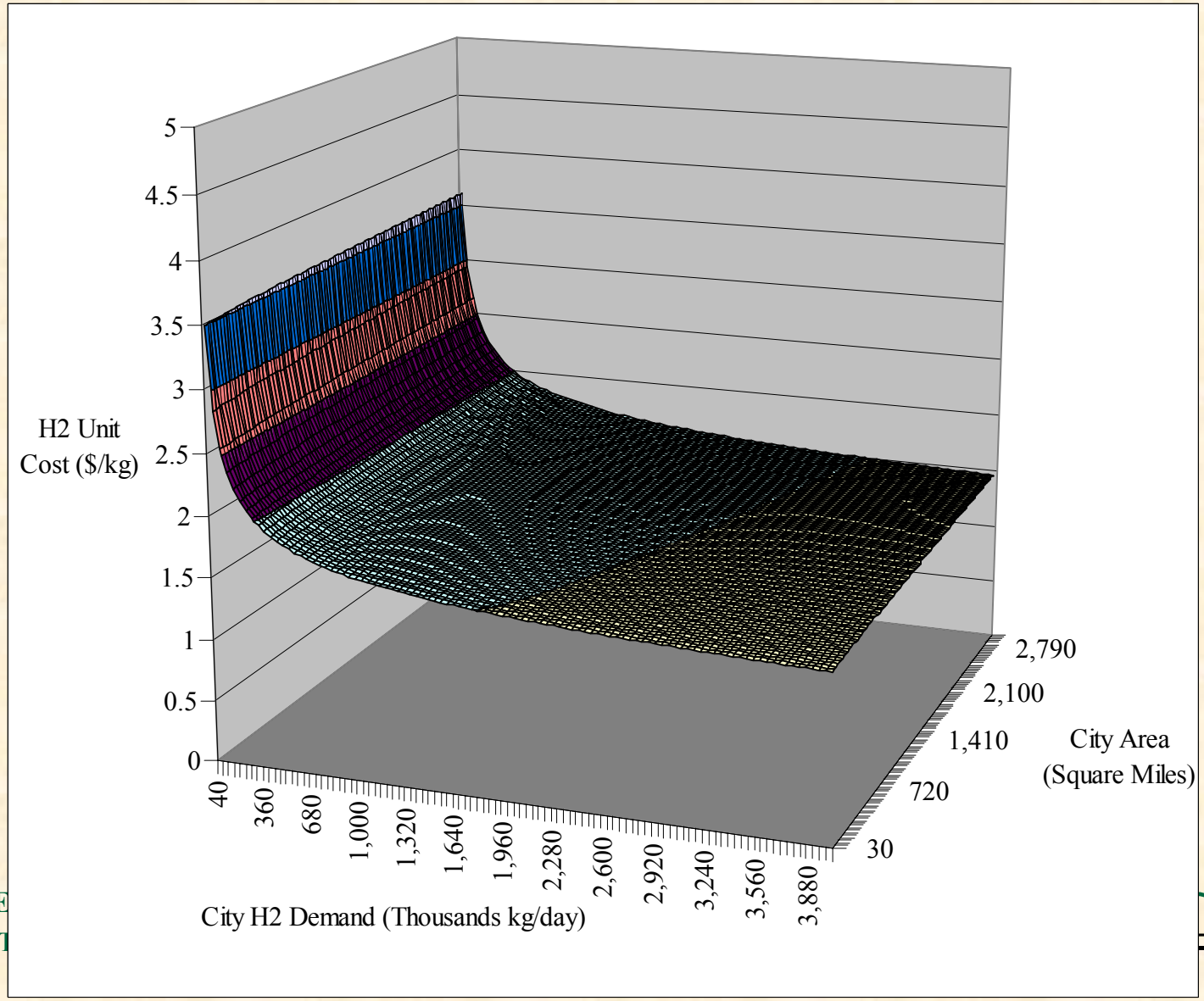


Delivered Costs fall to ~$1.75/gge by 2020

Liquid truck transport excluding forecourt costs, plant at city gate.



Adding costs of 1,500kg/d forecourts and 100 km distance to city gate.



Compressed gas trucks (3,000 psi) delivering to 100 kg/d forecourts.